

SUPERSYMMETRY VERSUS PRECISION EXPERIMENTS REVISITED

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We study constraints on the Minimal Supersymmetric Standard Model from electroweak experiments. We find that the light sfermions always make the fit worse than the Standard Model, while the light chargino generally make the fit slightly better through the oblique corrections. The best overall fit to the precision measurements are found when the mass of lighter chargino is about 100 GeV and the $SU(2)_L$ doublet sfermions are all much heavier. We find the slight improvement of the fit over the SM, where the total χ^2 of the fit decreases by about one unit.

1 Electroweak observables in the MSSM

Precision measurements of the electroweak observables on the Z -pole at LEP1 and SLC ¹, and the W -boson mass at LEP2 and Tevatron ² are expected to give the stringent constraints on the Minimal Supersymmetric Standard Model (MSSM). The supersymmetric (SUSY) contributions to the electroweak observables are given through the oblique corrections and the process specific vertex/box corrections. It has been shown that the Z -pole observables are conveniently parametrized in terms of two oblique parameters S_Z and T_Z ³, and the $Zf_\alpha f_\alpha$ vertex corrections, where f denotes the fermion species and α is their chirality. The oblique parameters S_Z and T_Z are related to the S and T parameters ⁴,

$$S_Z \equiv S + R - 0.064x_\alpha, \quad (1)$$

$$T_Z \equiv T + 1.49R - \frac{\Delta\bar{\delta}_G}{\alpha}, \quad (2)$$

where $x_\alpha = \frac{1/\alpha(m_Z^2) - 128.90}{0.09}$ and $\Delta\bar{\delta}_G/\alpha$ parametrize the hadronic uncertainty of the QED coupling and the corrections to the μ -decay constant, respectively. The parameter R is introduced as the difference of the Z -boson propagator corrections between $q^2 = m_Z^2$ and $q^2 = 0$. For convenience of later analysis, we introduce ΔS_Z and ΔT_Z as the shifts from S_Z and T_Z at the SM reference point,

$$m_t = 175 \text{ GeV}, m_{H_{\text{SM}}} = 100 \text{ GeV}, \alpha_s(m_Z) = 0.118 \text{ and } 1/\alpha(m_Z^2) = 128.90,$$

$$\Delta S_Z = \Delta S + \Delta R - 0.064x_\alpha, \quad (3)$$

$$\Delta T_Z = \Delta T + 1.49\Delta R - \frac{\Delta\bar{\delta}_G}{\alpha}. \quad (4)$$

In addition to ΔS_Z and ΔT_Z , we adopt the W -boson mass $m_W(\text{GeV}) = 80.402 + \Delta m_W$ as the third oblique parameter instead of the U -parameter ⁴:

$$\Delta m_W = -0.288\Delta S + 0.418\Delta T + 0.337\Delta U + 0.012x_\alpha - 0.126\frac{\Delta\bar{\delta}_G}{\alpha}. \quad (5)$$

So the new physics contributions to the electroweak observables can be summarized by three oblique corrections $\Delta S_Z, \Delta T_Z$ and Δm_W , and the non-oblique corrections Δg_α^f and $\Delta\bar{\delta}_G$.

2 Quantum corrections in the MSSM

First we show the constraints on the oblique parameters from the experiments and study the SUSY contributions to them. Taking account of Δg_L^b which may have the non-trivial m_t -dependence even in the SM, we perform the 5-parameter fit ($\Delta S_Z, \Delta T_Z, \Delta m_W, \Delta g_L^b, \alpha_s(m_Z)$) and find

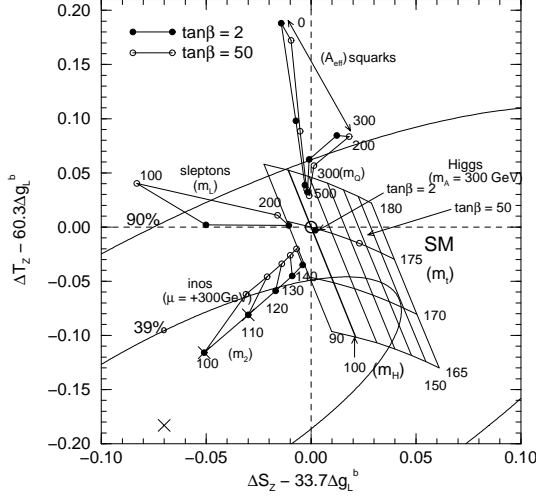


Figure 1. Supersymmetric contributions to $\Delta S_Z - 33.7\Delta g_L^b$ and $\Delta T_Z - 60.3\Delta g_L^b$. The symbol (x) denotes the best fit from the electroweak data. The 39% ($\Delta\chi^2 = 1$) and 90% ($\Delta\chi^2 = 4.61$) contours are shown. The SM predictions are given for $m_t = 165 \sim 180$ GeV and $m_{H_{SM}} = 90 \sim 150$ GeV.

the following constraint:

$$\left. \begin{aligned} \Delta S_Z - 33.7\Delta g_L^b &= -0.070 \pm 0.113 \\ \Delta T_Z - 60.3\Delta g_L^b &= -0.183 \pm 0.137 \end{aligned} \right\} \rho = 0.89, \\ \Delta m_W = 0.008 \pm 0.046, \\ \chi_{\min}^2 = 15.4 + \left(\frac{\Delta g_L^b + 0.00086}{0.00077} \right)^2, \quad (6)$$

where d.o.f. = 19 - 5 = 14. We show the supersymmetric contributions to $\Delta S_Z - 33.7\Delta g_L^b$ and $\Delta T_Z - 60.3\Delta g_L^b$ individually for $\tan\beta = 2$ and 50 in Fig. 1. The complete oblique corrections in the MSSM are given by their sum.

The squark and slepton contributions are shown as functions of the soft SUSY breaking mass parameters $m_{\tilde{Q}}$ and $m_{\tilde{L}}$, respectively, by assuming that their universality between the left- and the right-handed components. The effects of the left-right mixing of the sfermions are examined by introducing the effective A -parameter, $A_{\text{eff}} \equiv A_{\text{eff}}^t = A_{\text{eff}}^b$. For example, in the case of the stop, A_{eff} is given by $A_{\text{eff}} = A_t - \mu \cot\beta$. It can be seen from the

figure that the squark contribution makes the fit worse, because it always makes ΔT_Z larger than the SM. The presence of the left-right mixing (*i.e.* non-zero A_{eff}) make the squark contribution to the ΔT_Z -parameter slightly mild. The slepton contribution also makes the fit worse through the negative contribution to ΔS_Z . We find that the contributions from the left-handed sfermions to ΔS_Z and ΔT_Z are much larger than those from the right-handed sfermions.

We show the MSSM Higgs boson contributions to the oblique parameters for the CP -odd Higgs scalar mass $m_A = 300$ GeV and the SUSY breaking mass parameter $m_{\text{SUSY}} = 1$ TeV, which appears in the effective Higgs potential. The lightest Higgs boson mass m_h in the figure is 106 GeV for $\tan\beta = 2$, and 129 GeV for $\tan\beta = 50$. We can see that the MSSM Higgs boson contributions to $(\Delta S_Z, \Delta T_Z)$ behave like the SM Higgs boson for $m_A \gtrsim 300$ GeV.

We show the chargino/neutralino contributions to $(\Delta S_Z, \Delta T_Z)$ as a function of the wino mass M_2 and for the higgsino mass $\mu = 300$ GeV. The points with the (x) symbol in the figure are excluded from the direct search limit of the chargino mass (~ 90 GeV) at the LEP2 experiments. The chargino/neutralino contributions show the negative ΔS_Z and ΔT_Z , which may improve the fit over the SM. This is essentially because of ΔR which resides both in ΔS_Z and ΔT_Z . We find that the chargino contribution to ΔR is negative and large as compared to the sfermion contributions. For example, the contribution of the wino-like chargino to ΔR has the singularity $1/\sqrt{4M_2^2/m_Z^2 - 1}$ when M_2 is close to a half of m_Z . On the other hand, when $4M_2^2/m_Z^2 \gg 1$, ΔR is suppressed as m_Z^2/M_2^2 , but the coefficient of the wino contribution is found to be about 90 times larger than that of the right-handed slepton contribution. This large negative contribution to ΔR makes both ΔS_Z and ΔT_Z significantly negative when a relatively light chargino exists.

Beside the oblique corrections, we have studied the non-oblique corrections such as the Zff vertex corrections and/or the vertex/box corrections to the μ -decay process in detail ³, and we found no improvement of the fit over the SM through the non-oblique corrections. Then, the best fit of the MSSM may be found when all sfermions and Higgs bosons are heavy enough, while the chargino is relatively light so that the radiative corrections in the MSSM are dominated by the chargino contribution to the oblique parameters. We perform the global fit to all electroweak data in the MSSM by assuming that all sfermions and heavy Higgs bosons masses are 1TeV. Under this assumption, we show the total χ^2 in the MSSM as a function of the lighter chargino mass $m_{\tilde{\chi}_1^-}$ for $\tan\beta = 2$ and $M_2/\mu = 0.1, 1$ and 10 in Fig. 2. The decoupling in the large SUSY mass limit is examined by comparing the MSSM fit with the SM fit at $m_{H_{SM}} = m_h = 106\text{GeV}$ rather than the SM best fit at $m_{H_{SM}} = 117\text{GeV}$. When the lighter chargino mass is around its lower mass bound from the LEP2 experiment, we find the slight improvement of the fit over the SM, where the total χ^2 decreases by about one unit. The case of $\tan\beta = 50$ shows the similar behavior ³.

3 Summary

We have studied constraints on the MSSM from the electroweak precision experiments. Owing to the negative large contribution to ΔT_Z from the light chargino, the improvement of the fit over the SM is expected, if the left-handed sfermions are heavy enough to decouple from the electroweak processes. The global fit of the MSSM show that, if the masses of all sfermions and heavy Higgs bosons are 1 TeV, the total χ^2 in the MSSM decreases by about one unit comparing with the SM when the lighter chargino mass is close to its direct search limit from LEP2.

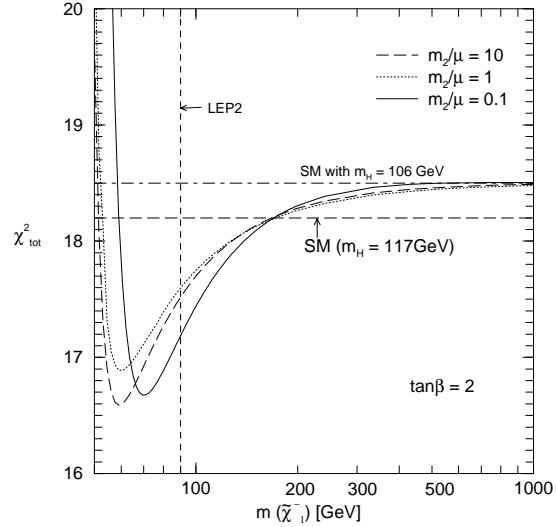


Figure 2. The total χ^2 in the MSSM as a function of the lighter chargino mass $m_{\tilde{\chi}_1^-}$ for $\tan\beta = 2$. The SM best fit ($\chi^2 = 18.2$) is shown by the dashed horizontal line. The dot-dashed horizontal line shows the SM fit using $m_{H_{SM}} = 106\text{ GeV}$ which is the lightest Higgs boson mass predicted in the MSSM. Three different M_2 - μ ratio (10, 1, 0.1) are studied. The bound on $m_{\tilde{\chi}_1^-}$ from the LEP2 experiment is shown by the dashed vertical line.

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